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A STUDY OF AN INVENTORY SYSTEM FOR CONTROL OF PERISHABLE TOOLS

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SUMMARY

The purpose of this study was the formulation of a computer-maintained system of inventory control of perishable tools. Actual data from a perishable tool inventory was used in a general example of the procedures and analysis required within the system.

The actual data consisted of the demands and lead time for two groups of tools; grinding wheels and fasteners. The demand data was tested for conformance to a theoretical probability distribution. The Poisson distribution was used as a model and a Chi-square test was made for goodness of fit. The demand data was found to be in close agreement to a Poisson probability distribution.

The lead time data was tested for homogeneity by a control chart test. The lead times for the tool types within each group were shown to be in control so the lead times were pooled to form composite lead times for each group. The composite lead time data did not follow a known probability distribution. Therefore, observed ratios for the lead time distributions were used in further computations.

The probability of demand during lead time was computed from a multinomial expansion. The multinomial expansion was utilized since the demands and the lead times

were variable.

Optimum order quantities and the reorder points derived for three tools through application of assumed cost values within a mathematical model. In turn, the levels of inventory were simulated through the use of the calculated optimum order quantities and reorder points.

These processes become a part of a proposed system of inventory control for perishable tools. The proposed system employs pre-punched cards at all stages of tool handling. This enables accurate, timely data to be generated for demand and lead time distributions. Also, tool usage (utilization of re-useable tools) is determined in the proposed system.

It is recommended that "stockpiling" (the accumulation of individual organizational inventories) be investigated. Stockpiling may result in incorrect order quantities through unrealistic demands and lead time.

CHAPTER I

INTRODUCTION

This is a study of a system of inventory control of perishable tools. Perishable or expendable tool inventories have tended to receive less emphasis in control systems than raw materials, goods-in-process, and finished goods inventories. Since these latter inventories constitute the major portion of inventory investment within an organization, it is not surprising that a lesser degree of emphasis be placed on perishable tool inventories. It also may account for the dearth of information on tool inventories, per se, in the literature. This lack of emphasis has resulted in a partial neglect of an area in which sizable investments and expenditures occur and wherein economies can be realized.

The objective of this study is to devise a system of inventory control of perishable tools which will be maintained by a computer. Data from a perishable tool inventory is examined and used in an example of procedures and elements which would be contained in a computer routine. The example is generally applicable.

Pertinent and timely information can be furnished from a computer-maintained inventory. The information will enable the organization to approach the goal of its inventory policies whether the maximum level of investment is limited, the optimum levels of inventory are sought, or the minimum associated costs (storage, procurement expenses, etc.) are desired.

The information provided should include order lead time, tool usage, tool life, and tool demands. Through the facts thus provided, optimum minimum and maximum levels of inventories for the given parameters can be established; the unused tools can be detected; the economical tools can be determined; and the anticipated expenditures for future production can be ascertained.

CHAPTER II

PROCEDURE

Collection of Data.--The collection of actual data for this study was afforded by limited access to the perishable-tool-inventory records of an aircraft manufacturer. The company had an annual expenditure in excess of one million dollars for these tools and the inventory consisted of more than 18,000 different types. Admittedly, the term "perishable tool" will be defined differently for each organization. In this study a tool was classified as "perishable" if it met any one of the following conditions: (1) each tool had an estimated life of 24 months or less; (2) each tool or set of tools cost $100 or less; and (3) the maintenance of records for individual, physical accountability of a tool was uneconomical and impractical.

Also, a distinction is made between tool usage and tool demand. Tool usage is the number of times which a tool is utilized and is applicable to re-usable tools. Tool demand denotes the request for a tool which is ordinarily not re-usable.

The demands, the usage and order lead times are obtained from historical data through necessity. Collection of the historical data in this study enabled a comparison of the collected data to known inventory theories. The vast number of tool types precluded any possibility of obtaining historical data on each. Although, "it is commonplace to find that 85 per cent of the annual dollar usage in a given inventory is concentrated in 15 per cent of the items of that inventory"[1] it was ruled infeasible to determine if these percentages (85 and 15) were approximated by the perishable tool inventory of the company.

Thus, two groups of tools were selected for the collection of historical data. The first group was comprised of ten types of grinding wheels and the second group was comprised of twenty types of fasteners. The selection of these two groups gave a divergence in cost and retained a comparable degree of activity.

Both groups of tools were purchased on a blanket purchase order. The blanket purchase order was approved for a specified number of tools and a selected vendor. This enabled the person responsible for maintaining the proper levels of inventory to personally place an order by telephone with the vendor. This circumvented the usual channels of placing an order and the resultant was

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[1] W. Evert Welch, Tested Scientific Inventory Control, Greenwich, Conn.: Management Publishing Corp., 1956, 19.

a reduction in lead time. A written purchase order was initiated the same day and forwarded to the vendor. Figure 1 depicts the flow of paper and tools.

Dates were not recorded when the tools left the receiving organization and entered the inspection organization. Fortunately, the dates were recorded when the tool stores organization received the tools. The recording of these dates was instituted at the beginning of the year 1959. The actual lead time prior to this year is indeterminable.

The transactions of the system were recorded by means of a business machine on a record card for each type of tool. The dates entered upon the record card were posting dates so it was necessary to obtain the actual dates from the tool requests and purchase orders.

Upon completion of the collection of the discernible actual dates and quantities, the intervals of time between the data were compiled in days. The intervals of time are as follows:

1. Interval between the placement of the purchase order and the receipt of the tools by the receiving organization;
2. Interval between the receipt of the tools by the receiving organization and the receipt of the tools by the tool stores organization.

The intervals of time are based on five days per week.

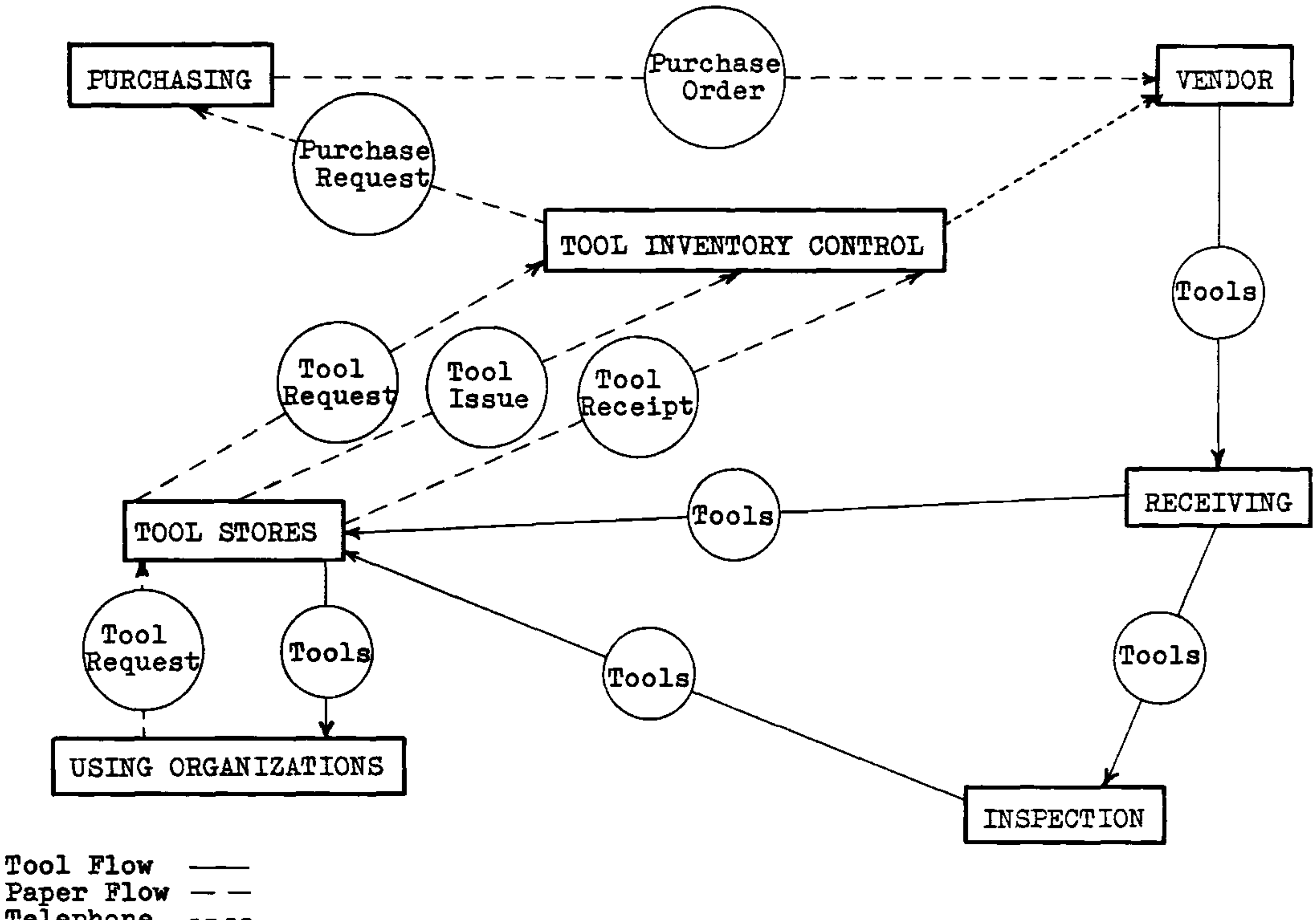

Figure 1. Flow Diagram of Tools and Paper

Saturdays, Sundays and holidays are excluded. There are a few instances when a Saturday or a Sunday date appeared. Since there was not an accessible manner to ascertain whether or not these dates were mistakes and there may have been instances of overtime work, a Saturday date was adjusted to Friday and a Sunday date was adjusted to Monday to establish conformity to the usual sense of a calendar week.

The dates, demands and time intervals for the ten most active types of fasteners are given in Table 1 through Table 10 and for the four most active types of grinding wheels in Table 11 through Table 14.

Test of Demand Distributions.--The distributions of the tool demands were tested for conformance to a theoretical probability distribution. A Poisson distribution was used as the model in the following manner:

$$p(d) = e^{-a}\frac{a^{d}}{d!}$$

where:

$p(d)$ = probability of d demands per day

d = number of demands per day, $d = 0, 1, 2, \ldots$

a = mean of the random variable d

$$\hat{a} = \frac{\sum_{d=0}^{N} f_d d}{\sum_{d=0}^{N} f_d} = \text{estimate of } a$$

N = maximum number of demands per day observed

f_d= number of observed days with d demands.

The theoretical frequency of demands was obtained by

$$f_t = p(d) \sum_{d=0}^{N} f_d$$

In turn, a Chi-square test was made for goodness of fit. The Chi-square value was computed from the following equation:

$$\sum_{j=1}^{3} \left[\frac{(f_o - f_t)^2}{f_t} \right]_j .$$

<u>Test of Lead Time Distributions.</u>—The distribution of the lead times for each type of tool within the two groups contained a small number of samples. Therefore, the lead times within each group were tested for homogeneity using

a control chart test.[2] On the basis of this test, the data was pooled to form lead times for the group.

Derivation of Probability of Demands During Lead Time.—The demands and the lead times were variable; thus, a multinomial expansion was used to compute the probability of demands during lead time. The multinomial expansion is as follows:

$$(1)\quad p(x) = \sum_{t_m = 0}^{M} p(t_m)\left[\sum_{\substack{\text{"all}\\ \text{possible}\\ \text{combinations"}}} \left(\frac{(t_m!)}{k_1!k_2! \ldots k_v!} \right) (p_{u_1})^{k_1}(p_{u_2})^{k_2} \ldots (p_{u_v})^{k_{t_m}} \right]$$

where:

$p(x)$ = probability of a demand for x units during lead time

t_m = lead time equal to m periods

M = maximum number of lead-time periods

$p(t_m)$ = probability of a lead time of m periods

$k_1 + k_2 + \ldots + k_v = t_m$

$k_1u_1 + k_2u_2 + \ldots + k_vu_v = x$

p_{u_1} = probability of a demand for u_1 units in one period of time.

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[2]Albert H. Bowker, Gerald J. Lieberman, Engineering Statistics, Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1960, 378-398.

"All possible combinations" means the number of combinations which can be formed from t_m values of u where the sum of the u's equals x. A specific example of the multinomial expansion for a probability of a demand for four units during lead time, with a demand distribution from zero through four units per period of lead time and a lead time distribution of one through four periods of time, being:

$$p(4) = p_{t_1}p_4 + p_{t_2}(2p_0p_4 + 2p_1p_3 + p_2^2) + p_{t_3}(3p_0^2p_4 + 6p_0p_1p_3 + 3p_0p_2^2 + 3p_1^2p_2) + p_{t_4}(4p_0^3p_4 + 12p_0^2p_1p_3 + 6p_0^2p_2^2 + 12p_0p_1^2p_2 + p_1^4).$$

Model for Order Quantity and Reorder Point.—The mathematical model[3] used for determining the optimum order quantity and the reorder point was:

$$(2) \qquad J = \frac{ICQ}{BD},$$

$$(3) \qquad Q^* = \frac{2D[S + BE(x > R)]}{IC}$$

$$(4) \qquad Q = \frac{2DS}{IC}$$

$$(5) \qquad E(x > R) = \sum_{x = R + 1}^{x\ max} (x - R)p(x)$$

[3]Robert B. Fetter, Winston C. Dalleck, Decision Models for Inventory Management, Homewood, Ill.: Richard D. Irwin, Inc., 1961, 17-18.

where:

$p(x)$ = probability of demand for x units during lead time

$P(x)$ = probability of a demand greater than x units during lead time = $p(x + 1) + p(x + 2) + \ldots + p(x \max)$

I = interest rate per year

C = unit cost

Q = order quantity

B = stockout cost per unit demanded but not available

D = expected yearly demand of units

S = procurement cost per order

Q^* = optimum order quantity

R = reorder point

$E(x > R)$ = expected number of units demanded but not available during lead time.

The steps to be followed in applying the equations are:

1. Calculate Q using equation (4)
2. Calculate J using equation (2)
3. Determine R from the probability of demand during lead time distribution such that R is the smallest value of x for which $P(x) \leq J$
4. Calculate $E(x > R)$ using equation (5)
5. Calculate Q^* using equation (3)

6. Repeat steps 2 through 5 until sufficient accuracy is achieved.

CHAPTER III

RESULTS AND CONCLUSIONS

<u>Inherent Weaknesses Within a Present System of Tool Inventory Control</u>.--The demands, the order lead times, and the usage may only be needed and applied in a refined inventory control system. The minimum and maximum levels of inventory in the inventory control system of the company, from which the data was obtained, are set by reviewing the record cards. The total number of units issued for the previous 60 days and 30 days are determined and, if these values appear logical, they become the maximum and minimum levels of inventory. Lead time is considered only if it is expected to be over 30 days. This procedure allows many individual judgments to be made and may result in improper inventory levels.

Another inherent detriment within the system is the use of the posting date rather than the actual date. The significance of this statement can be realized by referring to Table 1, Table 27, and Table 28. In Table 1, the issuances posted on April were actually issued in the period of March 31 through April 20, with the exception of April 16 and 17. The actual issuances of April 16 and April 17 were posted on April 29. In Table 27, the interval between

Order and Post has a range of 0-9 days; the interval between Stores and Post has a range of 0-44 days; the interval between Issue and Post has a range of 0-120 days. In Table 28, the interval between Order and Post has a range of 0-15 days; the interval between Stores and Post has a range of 1-23 days; the interval between Issue and Post has a range of 1-78 days. The actual lag in time is due to improper forwarding of documents, an accumulation of the documents at the bookkeeping machine or a combination of both. The result is an occasional stockout.

The occasional stockout poses the question of whether there is the natural tendency to "stockpile". Since there is only one source of supply for the using organizations (a captive demand), they will submit one or more additional issue requests if the original request is not filled within a reasonable time, or they will obtain more than is actually needed once the supply becomes available again. This factor was apparent in the compilation of the data.

The point to be stressed in this situation is that the realistic distributions and random demands are lost. Failure to consider this feature can result in false conclusions with resultant inappropriate levels of inventory.

Another factor which must be considered is the true amount issued. It will be noted in Table 1 through Table 14 that credits were not taken into consideration in determination of the total number of items issued. The credits are assumed to be the (unknown) under issuance of the desired amount and are entries to bring the reported inventory into accord with the physical inventory. By the same token, it is difficult to detect the over-issuance adjustments within the inventories. There is reason to suspect that some reported issuances are in reality adjustments. The suspicion cannot be substantiated for the suspected issuances are assigned to a specific using organization instead of an order number or an account for adjustments. The handling of adjustments in this manner is open to criticism and automatically raises the question of the validity of the data.

The demand distributions for the ten types of fasteners are given in Tables 1-A through 10-A. The demand distributions for the four types of grinding wheels are given in Tables 11-A through 14-A. Also, the average demand and the average interval of time between demands is presented in these tables.

Actual and Theoretical Demand Distributions.—It is set forth in the literature that the demand distributions of inventories are usually Poisson. Therefore, it was logical to test the actual distributions for conformance to the Poisson probability distribution. The distributions are given in Table 15 and Table 16 and the goodness-of-fit test is given in Table 17.

It will be noted that in Table 17 the levels of significance range from approximately 0.025 to approximately 0.90, with the majority of the levels of significance being near 0.50. This is a normal result for it would be expected that in a test of goodness of fit that a greater number of the values would fall around a central value of 0.50 with the number of values decreasing as they fell farther away from the central value in either direction, toward the extremes of 0 and 1.

The Chi-square test indicates that the actual demand data is in close agreement to a Poisson probability distribution. Thus, the computed probabilities can be used in the generation of the probability of demand during lead time.

Actual and Theoretical Lead Time Distributions.—The order lead times for the fasteners and the grinding wheels were subjected to control chart tests to see what data could be pooled. The $\bar{x}$ Control Chart for fasteners appears in Figure 2 and the σ Control Chart for fasteners appears in Figure 3. The data from which $\bar{x}$ was derived for the various types of fasteners and grinding wheels is presented in Table 21 and Table 22. Also, the value for $\bar{\bar{x}}$ and $\bar{\sigma}$ for each group is given at the end of these tables. The computed limits for each $\bar{x}$ are given in Table 23 and Table 25. The computed limits for each σ are given in Table 24 and Table 26.

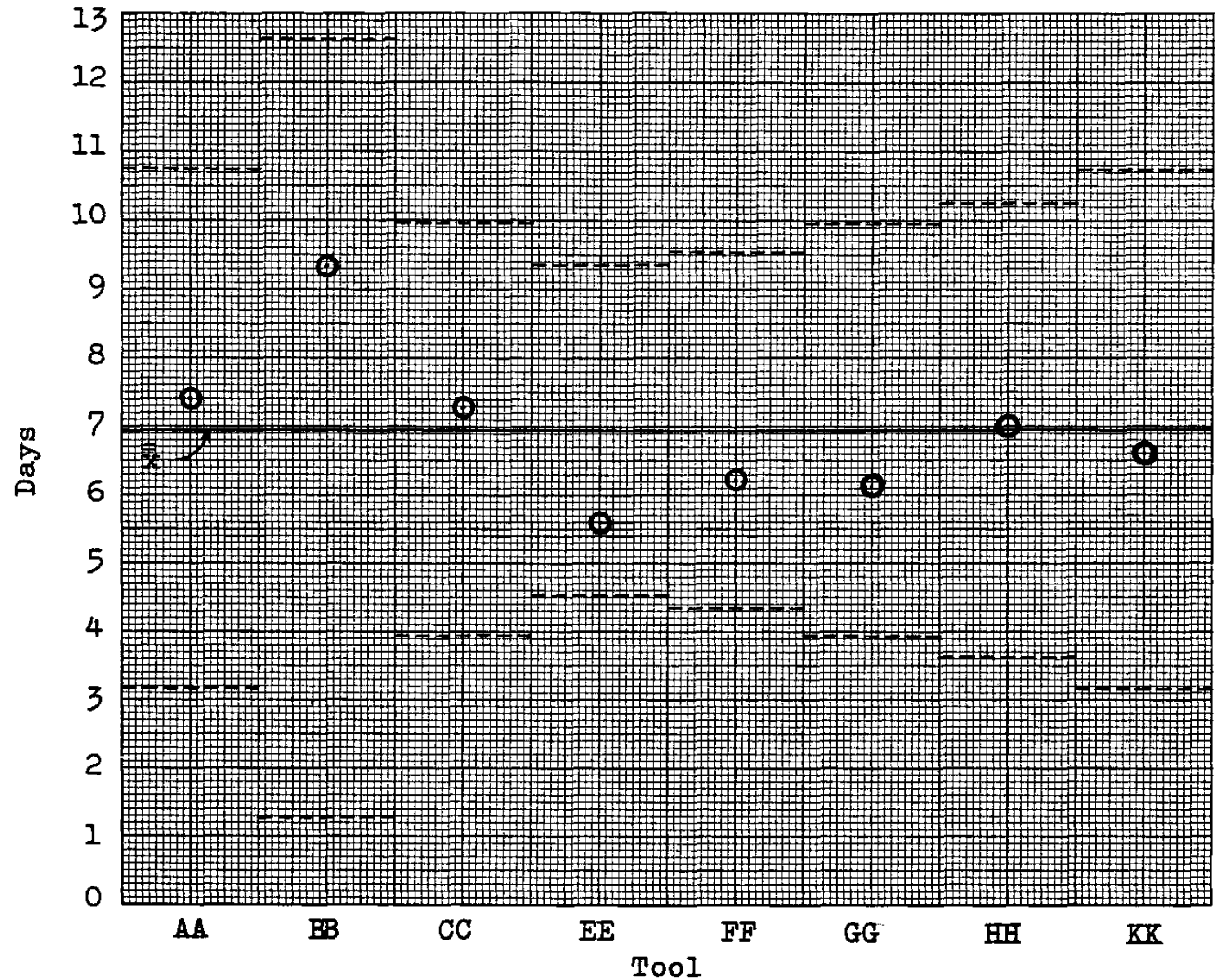


Figure 2. $\bar{x}$ Control Chart for Lead Time of Fasteners

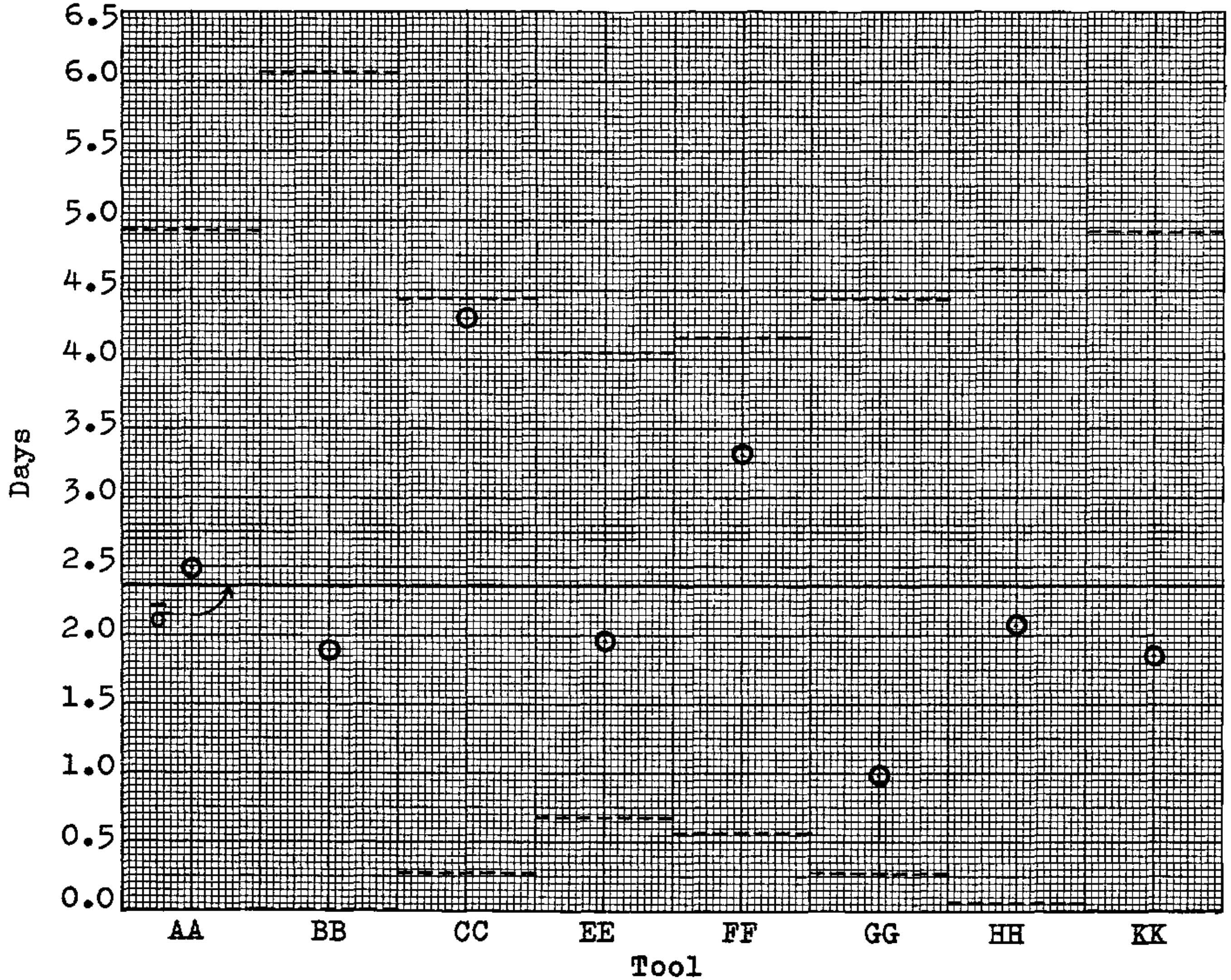


Figure 3. σ Control Chart for Lead Time of Fasteners

The data was found to be in control for each group. Since the placement of orders and the handling of the tools was the same for all types of tools within a group, the lead time data of the tool types was grouped to form composite lead time data for the group. The latter did not follow a known probability distribution for either group, although lead time often follows a normal distribution. The frequency distributions for the two groups are given in Figure 7, page 24.

It was then necessary to compute the ratio of the number of occurrences of a specific lead time to the total number of lead times. This gave a percentage which could be used in the multinomial expansion. The ratios are compiled in Table 18 and Table 19.

Probability of Demand During Lead Time.—The probabilities of demands during lead time were computed by use of multinomial expansion given in equation (1), the Poisson probability distributions, and the lead time ratios. The computed probabilities are presented in Table 20.

Inventory Simulation.—Three types of tools were selected for inventory simulation. The order quantity (Q*) and reorder point (R) for Tool B, Tool C, and Tool GG were calculated by use of equations (2) through (5). The actual cost factors were not available so cost estimates and assumptions were made. The assumed values for I, S, C, and B and the observed values for D are as follows:

	I	S	C	B	D
Tool B	0.15	15	200	30	23
Tool C	0.15	15	200	30	43
Tool GG	0.15	15	225	35	45.3.

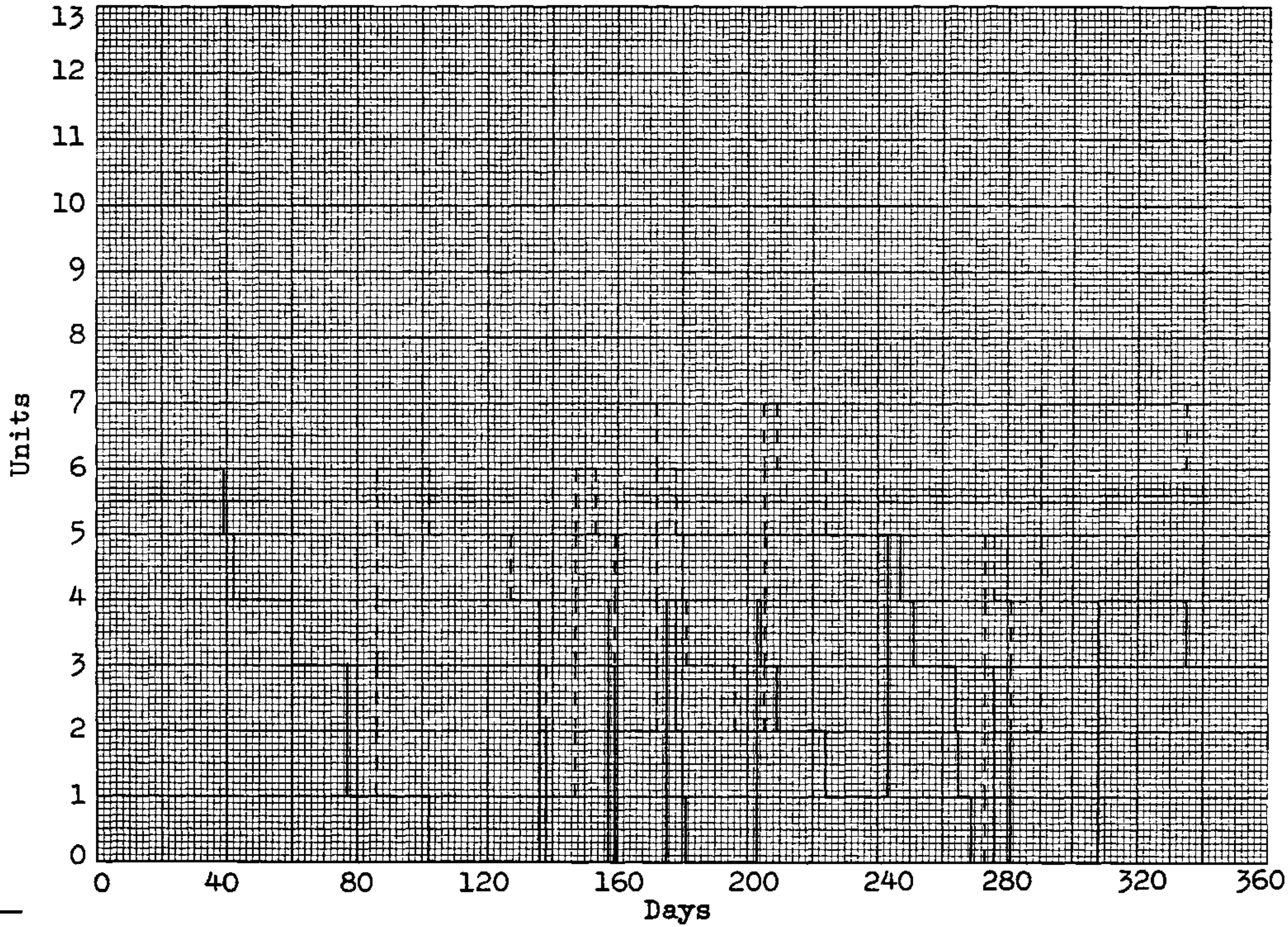
The value of C for GG was computed by 0.25 dollars per tool times 900 tools (average) per request. The value of D was 45.3 requests per year which is the quotient of

$$\frac{\text{40,780 tools issued per year}}{\text{900 (average) tools per request}}.$$

The levels of inventory were simulated through the use of Q^* and R for the three tools. The lead time used in the simulation are consistent with the actual lead times. The actual and theoretical inventories along with Q^* and R are shown in Figures 4, 5, and 6.

It will be noticed in Figure 4 for Tool B that a stockout appears with the theoretical inventory. This is consistent with the calculated values of $J = .226$ and $Q^* = 5$. With a value of $J = .226$, a stockout would be expected once every 4.4 orders which is almost identical to the average number of orders placed per year, i.e.

$$\text{avg. no. of orders/year} = \frac{\text{yearly demand}}{Q^*} = \frac{23}{5} = 4.6.$$



Actual ——
Theoretical - - -
$Q^* = 5$
$R = 2$

Figure 4. Actual and Theoretical Inventory Levels of Tool B

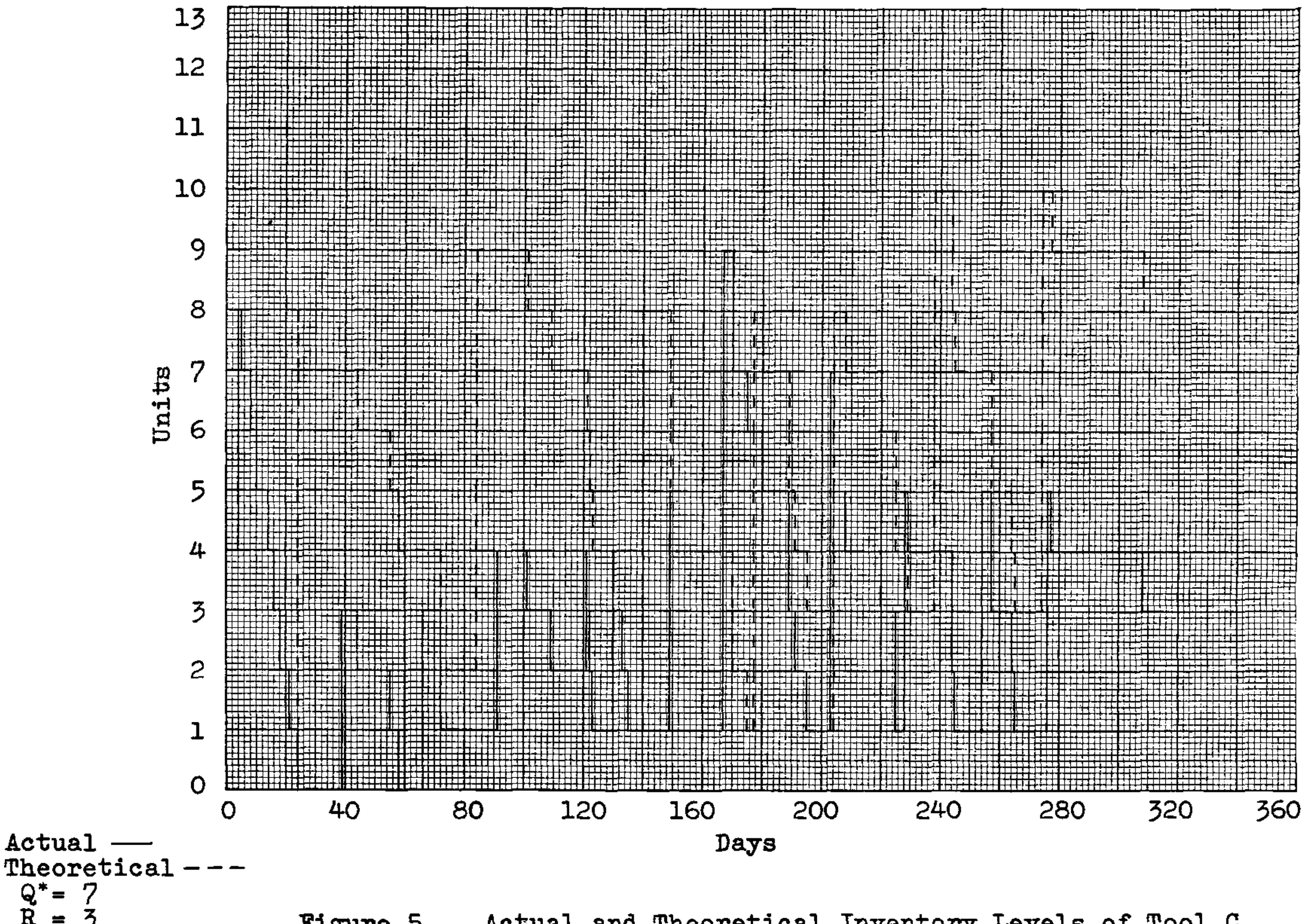
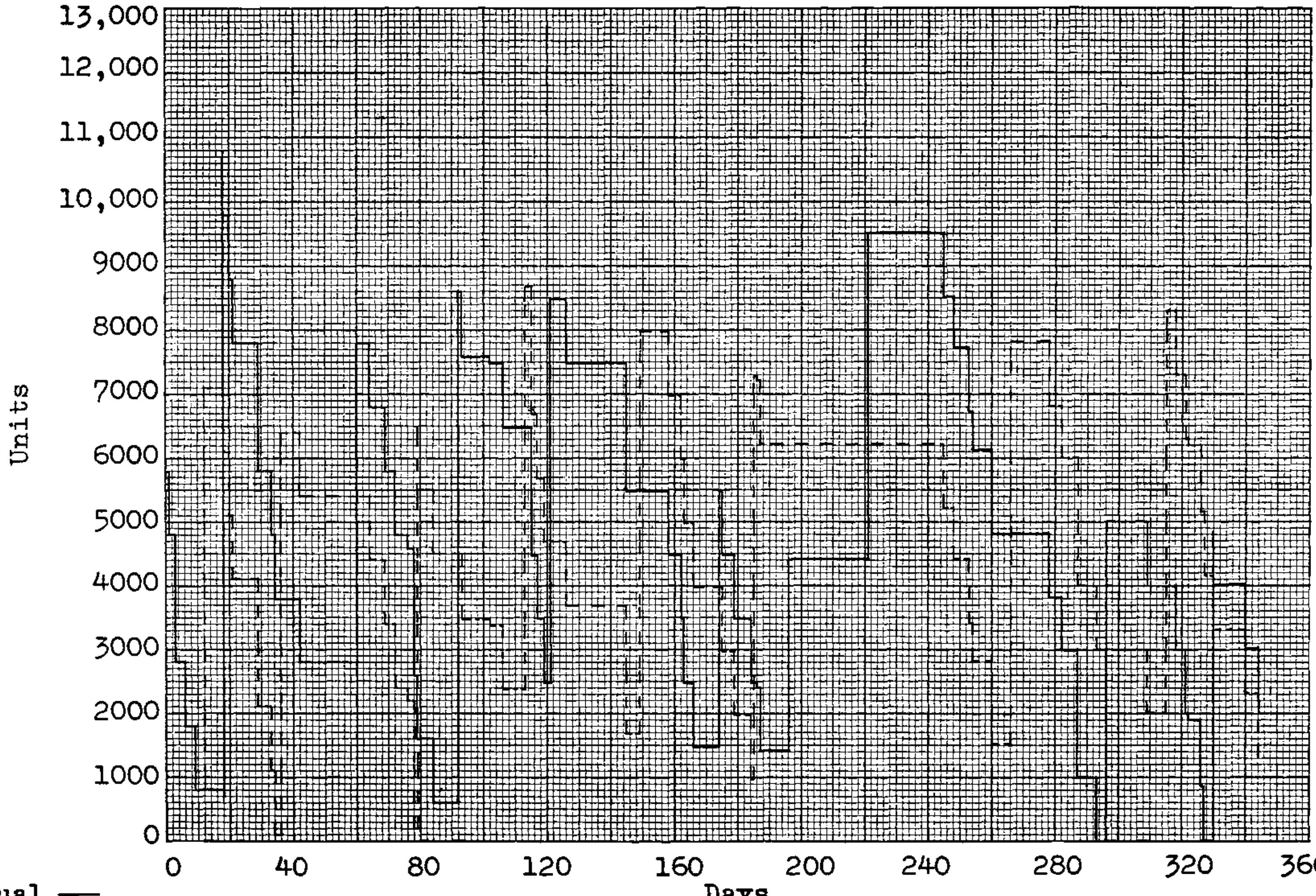
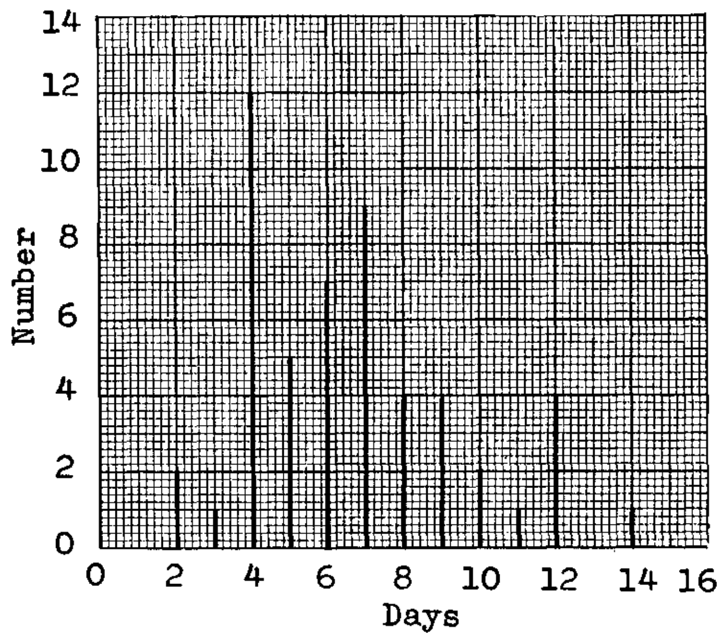


Figure 5. Actual and Theoretical Inventory Levels of Tool C

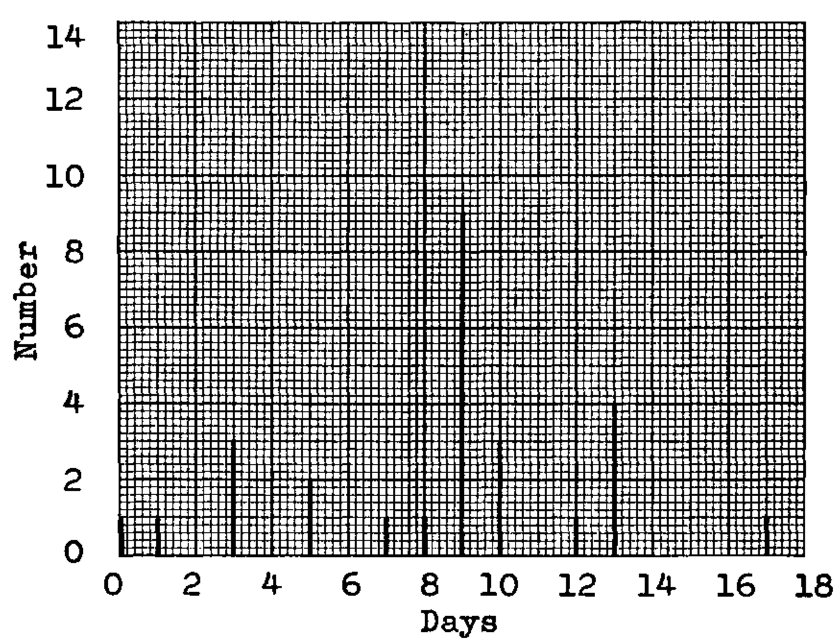


Actual ——
Theoretical - - -
Q*= 6300
R = 2700

Figure 6. Actual and Theoretical Inventory Levels of Tool GG



Fasteners



Grinding Wheels

Figure 7. Frequency Distributions for Lead Time

CHAPTER IV

A PROPOSED SYSTEM OF INVENTORY CONTROL

Any increase in the degree of control of inventories brings an increase in paper to be processed and in the personnel to process the paper. This, in turn, adds to the cost of the administration of the program and a point of diminishing returns is soon reached beyond which added growth of the system is impractical. There is always the desire for greater control but the desire is usually overshadowed by the cost. Often expanded, efficient control can be obtained by the use of a computer.

The following system of control for perishable tool inventories, using a computer, is advanced.

At the time the purchase order is placed with the vendor, cards are punched specifying the name, stock number, quantity, purchase price, cross-reference numbers and other pertinent information. One card carries the date the order is placed and the card is designated as the "on order card." Another card (receiving card) is forwarded to the receiving organization; another card (inspection card) is sent to the inspection organization, if required; another card (tool-stores-receipt card) is sent to the tool stores organization. Upon receipt of the tools within each successive organization, the respective receipt date and the number of tools is written on the card. The completed cards are collected; the written information is key-punched on the cards; the cards are processed by the computer each day. Thus, accurate and current lead times are obtained for use in the computation of the optimum order quantities and reorder points.

Tool demands are also generated by the use of pre-punched cards. In this instance, two classes of cards are used. One class is designated as "Issue" and the other is designated as "Return". Tools which are not returned to a tool crib for re-use require only the Issue Card, whereas the reusable or returned tools require both classes of cards.

The pre-punched cards are distributed to the various tool cribs. When a tool is withdrawn or issued, the date, the employee's number and organization number or the organization's number, and the number of tools is written on an Issue card bearing the same description as the tool. The same information is written on a Return card when the tool is returned to the tool crib. These cards are collected and processed daily.

During the processing of the records, the quantity of tools remaining in inventory is compared to R. The tool number, the quantity to be ordered and R are written out, if the inventory value is less than R. This list gives the tools and amount to be ordered each day.

The computer is programmed to calculate:

1. the Poisson distributions for the demands
2. the lead time distributions or ratios
3. the probability of demand during lead time
4. the value of Q^* and R,

and to update the frequency distributions for the demands and lead times.

The advantages of the system are numerous. Information is processed and presented with a minimum elapse of time. Therefore, decisions can be made and actions can be taken when they will have a meaningful effect. The decisions and actions will occur before a critical situation has the opportunity to arise.

The card which is punched by the receiving organization will signal the arrival of the ordered tools. If the tools are needed immediately, they can be expedited. Thus, the opportunity of overlooking the critical tools is minimized. The card also signals the accounts payable organization that the tools have arrived and have been accepted, provided the tools do not require inspection. This procedure minimizes the possibility of passing beyond a discount date.

The dates provided by the system furnish accurate and easily compiled information from which statistically correct demand and lead time distributions can be determined. The intervals of time thus calculated also point out areas where attention should be focused.

It is a simple matter to review the elements of the lead time. If the element of lead time for a particular organization is of a long interval of time, it may be an indication that the organization is understaffed or that inefficiency is prevalent. Investigation will determine the reason and corrective action can be instituted. Any reliable reduction in lead time will mean a reduction in inventory levels.

The "Issue" and "Return" cards enable the tools withdrawn by an employee to be debited and credited to his record. Thus, the employee is fully responsible for any tool which is withdrawn and the tools charged to a specific employee are on a current, central record.

The usage or turnover of tools is also determined from the Issue and Return cards. This feature may require the establishment of definite procedures, such as the length of time which a tool may be kept. Actually, the term "usage" may be misleading for it is possible for a tool to be withdrawn and still not be used for its functional purpose. The term "turnover" defines the intent more appropriately. The turnover of tools enables the detection of tools which should no longer be carried in the inventory; it is an indicator of the life of the tool;

it points out those tools which require a larger inventory.

Additionally, the Issue cards could be of assistance in plant layout. Since the organization number is entered on the card, it is possible to determine which organizations make the greatest use of the tool cribs. The placement of the tool cribs can then be placed in the most advantageous locations.

CHAPTER V

RECOMMENDATIONS

The exigencies of time may not allow investigation of some questions or problems which arise during an analysis. The effects of "stockpiling" on inventory levels is one such question. It would be interesting to know how it affects the demand distribution. A significant change in the demand distribution will cause the order quantity and the reorder point to change. It is strongly recommended that this area be investigated.

The lead time in this study was found not to follow any theoretical distributions so observed ratios were used. Another method which could have been used was a cumulative frequency distribution of the lead time. This would have distributed a proportion of the total number of lead times to all discrete lengths of time within the lead time range.

In the proposed system of inventory control, a mark-sense card was not mentioned. This form of information transfer could be quite adaptable to a tool inventory control system.

APPENDIX I

Table 1. Demand for Tool AA

Actual Issuance			Posted Issuance		
Date Issued	Number Issued (Credit)	Interval Between Issues (Days)	Date Issued	Number Issued (Credit)	Interval Between Issues (Days)
1959			1959		
Jan. 2	100	-	Jan. 9	200	-
				100	-
7	200	3	20	100	7
14	100	5			
Feb. 5	100	16	Feb.10	100	15
12	400	5	17	400	5
23	200	7	24	200	5
25	100	2			
27	600	2			
Mar.31	200	22	Mar. 6	100	8
				600	-
Apr. 1	200	1	Apr.20	400	31
3	100	2		500	-
8	200	3		200	-
9	200	1		200	-
10	400	1		200	-
13	500	1		200	-
16	200	3		100	-
17	25	1		200	-
20	200	1	29	200	-
30	200	8		25	7
May 4	200	2	May 11	200	8
				200	-
12	200	6	19	200	6
13	30	1		30	-
?	200	-			
Jun. 3	200	14	Jun.12	200	17
10	200	5		200	-
11	400	1		200	-
12	(200)		18	(200)	
15	200	2	18	400	4
29	200	10		200	-

Table 1. Demand for Tool AA

Actual Issuance			Posted Issuance		
Date Issued	Number Issued (Credit)	Interval Between Issues (Days)	Date Issued	Number Issued (Credit)	Interval Between Issues (Days)
1959			1959		
Jul. 21	200	15	Jul. 8	200	13
24	200	3	23	200	11
	400	-			
30	400	4	29	200	4
				400	-
			Aug. 11	400	9
Sep. 1	200	23	Sep. 3	200	17
14	72	8	16	72	8
24	200	8	30	200	10
	200	8		200	-
Nov. 12	200	35	Nov. 18	200	35
Dec. 21	200	26	Dec. 29	100	26
22	100	1		200	-
28	200	2			
30	200	2			
1960			1960		
			Jan. 5	200	4
				200	-
Feb. 2	173	23	Feb. 10	173	26
22	100	14	24	100	10
Mar. 22	300	21	Mar. 23	300	20
Apr. 7	50	12	Apr. 8	50	12
Total	9450	322		9450	318

Table 1-A. Demand Distribution, Average Demand and Average Interval for Tool AA

Demand Distribution	
Times Issued	Number Issued
1	25
1	30
1	50
1	72
7	100
1	173
25	200
1	300
5	400
1	500
1	600
Total 45	

Average Demand

$$\frac{9450}{45} = 210 \text{ Units}$$

Average Interval

$$\frac{322}{42} = 8 \text{ Days}$$

Table 2. Demand for Tool BB

Date Issued (1959-1960)	Number Issued	Interval Between Issues (Days)
1959		
Jan. 7	200	-
14	200	5
Feb. 13	200	22
17	50	2
Apr. 16	200	42
May 4	200	12
7	400	3
18	200	7
Jun. 15	200	19
Jul. 23	200	27
27	200	2
30	400	3
Aug. 12	200	9
Nov. 12	200	65
1960		
Feb. 18	200	66
Mar. 8	200	13
21	200	9
22	200	1
25	50	3
31	100	4
Apr. 14	300	10
Total	4300	324

Table 2-A. Demand Distribution, Average Demand and Average Interval for Tool BB

Demand Distribution

Times Issued	Number Issued
2	50
1	100
15	200
1	300
2	400
Total 21	

Average Demand

$$\frac{4300}{21} = 205 \text{ Units}$$

Average Interval

$$\frac{324}{20} = 16 \text{ Days}$$

Table 3. Demand for Tool CC

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Jan. 5	1000	-
6	1000	1
	1000	-
14	200	6
15	200	1
Feb.11	1000	19
Mar. 6	1000	17
Apr.22	(400)	
Jul. 8	1000	86
20	1000	8
22	1000	2
Aug.20	1000	21
25	1000	3
Sep. 3	1000	7
	1000	-
8	1000	2
Oct.22	1000	32
Nov. 6	1000	11
19	2000	9
Dec.16	1000	18
31	(2000)	
1960		
Jan. 8	1000	14
22	1000	10
25	200	1
Feb. 5	500	9
18	1000	9
26	800	6
29	1000	1
Mar.15	1000	11
16	1000	1
18	1000	2
28	1000	6

Table 3. Demand for Tool CC

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1960		
Apr. 6	100	7
11	1000	3
12	1000	1
19	1000	5
May 4	1000	11
6	1000	2
	1000	-
11	(1650)	
13	1000	5
Total	35000	347

Table 3-A. Demand Distribution, Average Demand and Average Interval for Tool CC

Demand Distribution	
Times Issued	Number Issued
1	100
3	200
1	500
1	800
31	1000
1	2000
Total 38	

Average Demand

$$\frac{35000}{38} = 921 \text{ Units}$$

Average Interval

$$\frac{347}{34} = 10 \text{ Days}$$

Table 4. Demand for Tool DD

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Jan. 6	760	-
Feb. 13	800	28
26	800	9
Apr. 20	200	37
21	200	1
May 12	24	15
Jun. 3	200	15
9	800	4
15	100	4
	800	-
16	800	1
Jul. 9	800	16
Aug. 6	800	20
14	800	6
Sep. 1	800	12
2	800	1
4	800	2
21	400	10
	800	-
Nov. 18	500	42
Dec. 31	(242)	-
1960		
Jan. 29	800	48
Mar. 8	500	27
Apr. 15	500	28
25	500	6
Total	14284	332

Table 4-A. Demand Distribution, Average Demand and Average Interval for Tool DD

Demand Distribution

Times Issued	Number Issued
1	24
1	100
3	200
1	400
4	500
1	760
13	800
Total 24	

Average Demand

$$\frac{14284}{24} = 595 \text{ Units}$$

Average Interval

$$\frac{332}{21} = 16 \text{ Days}$$

Table 5. Demand for Tool EE

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Jan. 5	1000	-
6	1000	1
7	1000	1
13	1000	4
14	500	1
	1000	-
30	500	12
Feb. 5	500	4
10	1000	3
25	1000	11
26	1000	1
Mar. 11	2000	9
13	1000	2
17	1000	2
20	1000	3
Apr. 6	1000	11
17	200	9
20	1000	1
21	1000	1
	1000	-
?	1000	-
29	1000	6
May 4	1000	3
12	24	6
13	1000	1
22	1000	7
?	100	-
25	500	1
Jun. 4	1000	7
11	2000	5
19	163	6
29	1000	6
Jul. 9	1000	7

Table 5. Demand for Tool EE

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Aug. 17	200	27
?	1000	-
25	1000	6
28	1000	3
Sep. 2	100	3
	1000	-
	1000	-
8	200	3
	1000	-
9	289	1
14	1000	3
16	1000	2
24	1000	6
	1000	-
Oct. 27	1000	23
30	1000	3
Dec. 14	1000	30
17	1000	3
22	1000	3
28	1000	2
31	700	3
	1000	-
1960		
Jan. 6	1000	3
11	1000	3
Feb. 17	1000	27
25	1000	6
Mar. 4	1000	6
7	1000	1
	1000	-
15	1000	6
28	1000	9
Apr. 5	1000	6
6	100	1
15	100	7
?	1000	-
19	1000	2
May 18	824	21
	1000	-
Total	62000	350

Table 5-A. Demand Distribution, Average Demand and Average Interval for Tool EE

Demand Distribution	
Times Issued	Number Issued
1	24
4	100
1	163
3	200
1	289
4	500
1	700
1	824
53	1000
2	2000
Total 71	

Average Demand

$$\frac{62000}{71} = 873 \text{ Units}$$

Average Interval

$$\frac{350}{61} = 6 \text{ Days}$$

Table 6. Demand for Tool FF

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Jan. 5	50	-
14	500	7
Feb. 17	500	24
?	500	-
?	500	-
Mar. 17	964	20
19	50	2
May 20	500	44
?	500	-
Jun. 15	500	17
Jul. 9	500	17
17	1000	6
23	418	4
Aug. 6	500	10
11	500	3
28	500	13
Sep. 1	500	2
16	500	10
Oct. 19	1000	23
Nov. 4	100	12
11	500	5
Dec. 16	300	24
31	(700)	-
1960		
Feb. 11	382	38
16	800	3
18	800	2
Mar. 8	800	13
9	800	1
24	400	11

Table 6. Demand for Tool FF

Date Issued (1960)	Number Issued (Credit)	Interval Between Issues (Days)
1960		
Apr. 6	100	9
14	200	6
15	300	1
25	202	6
	998	-
May 4	400	7
Total	17064	340

Table 6-A. Demand Distribution, Average Demand and Average Interval for Tool FF

Demand Distribution

Times Issued	Number Issued
2	50
2	100
1	200
1	202
2	300
1	382
2	400
1	418
14	500
4	800
1	964
1	998
2	1000
Total 34	

Average Demand

$$\frac{17064}{34} = 502 \text{ Units}$$

Average Interval

$$\frac{340}{32} = 11 \text{ Days}$$

Table 7. Demand for Tool GG

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Jan. 2	1000	-
6	1000	2
	1000	-
9	1000	3
14	1000	3
27	1000	9
29	1000	2
30	1000	1
Feb. 11	1000	8
11	1000	-
17	1000	4
18	1000	1
Mar. 2	1000	8
Apr. 1	1000	22
8	1000	5
13	1000	3
17	200	4
21	1000	2
	1000	-
22	1000	1
29	1000	5
May 12	24	9
12	1000	-
25	100	9
Jun. 1	1000	4
12	1000	9
	1000	-
16	1000	2
18	1000	2
29	1000	7
Jul. 27	1000	19
	1000	-
Aug. 13	1000	13
19	1000	4
20	1000	1
25	1000	3

Table 7. Demand for Tool GG

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Sep. 8	1000	9
14	1000	4
21	1000	5
23	50	2
24	1000	1
Dec. 16	1000	58
21	800	3
30	1000	5
31	600	1
1960		
Jan. 11	300	6
	1000	-
Feb. 4	1000	18
10	826	4
17	2000	5
25	1000	6
Mar. 18	1000	16
31	1000	9
Apr. 5	1000	3
6	100	1
12	36	4
	1000	-
13	1000	1
18	850	3
May 2	1000	10
6	1000	4
Total	54886	343

Table 7-A. Demand Distribution, Average Demand and Average Interval for Tool GG

Demand Distribution

Times Issued	Number Issued
1	24
1	36
1	50
2	100
1	200
1	300
1	600
1	800
1	826
1	850
49	1000
1	2000
Total 61	

Average Demand

$$\frac{54886}{61} = 900 \text{ Units}$$

Average Interval

$$\frac{343}{52} = 7 \text{ Days}$$

Table 8. Demand for Tool HH

Date Issued (1959-1960)		Number Issued (Credit)	Interval Between Issues (Days)
1959			
Jan.	14	500	-
	15	500	1
	16	1000	1
Feb.	3	500	12
	16	500	9
Mar.	3	500	11
	11	500	6
Apr.	7	500	19
	8	500	1
	15	1000	5
May	4	500	13
Jun.	1	500	19
	10	1000	7
	15	500	3
	18	500	3
Aug.	11	500	37
Sep.	2	500	16
	21	500	12
	23	50	2
	?	100	-
	24	150	1
Oct.	1	500	5
Dec.	16	500	53
	28	500	6
1960			
Jan.	8	500	8
Feb.	4	800	19
	5	500	1
Mar.	7	400	21
Apr.	6	100	22
		800	-
	21	800	11
	Total	16200	324

Table 8-A. Demand Distribution, Average Demand and Average Interval for Tool HH

Demand Distribution	
Times Issued	Number Issued
1	50
2	100
1	150
1	400
20	500
3	800
3	1000
Total 31	

Average Demand

$$\frac{16200}{31} = 523 \text{ Units}$$

Average Interval

$$\frac{324}{29} = 11 \text{ Days}$$

Table 9. Demand for Tool JJ

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Jan. 9	1000	-
26	1000	11
Feb. 17	1000	16
26	1000	7
Apr. 17	200	36
21	1000	2
22	1000	1
May 12	24	14
Jun. 16	1000	24
29	1000	9
Jul. 15	100	11
27	1000	8
Aug. 24	100	20
Sep. 8	1000	10
Dec. 28	1000	76
31	(424)	-
1960		
Jan. 22	1000	18
Mar. 10	1000	34
Apr. 6	50	19
	100	-
11	1000	3
12	36	1
May 12	1000	22
Total	15610	342

Table 9-A. Demand Distribution, Average Demand and Average Interval for Tool JJ

Demand Distribution	
Times Issued	Number Issued
1	24
1	36
1	50
3	100
1	200
15	1000
Total 22	

Average Demand

$$\frac{15610}{22} = 710 \text{ Units}$$

$$\frac{342}{20} = 17 \text{ Days}$$

Table 10. Demand for Tool KK

Date Issued (1958-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1958		
Dec. 23	500	-
	500	-
	500	-
31	500	4
1959		
Jan. 14	500	9
15	500	1
23	500	6
29	500	4
?	500	-
Feb. 4	500	4
18	500	10
23	1000	3
Mar. 9	500	10
	1000	-
17	500	6
Apr. 13	500	19
17	200	4
20	500	1
30	500	8
May 12	24	8
?	100	-
Jun. 9	500	19
15	500	4
26	500	9
Aug. 7	1500	29
10	188	1
24	50	10
Sep. 16	500	16
Oct. 16	450	22
27	500	7
Nov. 24	500	20
Dec. 31	488	24
	1000	-

Table 10. Demand for Tool KK

Date Issued (1960)	Number Issued (Credit)	Interval Between Issues (Days)
1960		
Jan. 15	800	10
Mar. 14	600	41
25	200	9
Apr. 5	800	7
6	50	1
21	800	11
Total	20250	337

Table 10-A. Demand Distribution, Average Demand and Average Interval for Tool KK

Demand Distribution	
Times Issued	Number Issued
1	24
2	50
1	100
1	188
2	200
1	450
1	488
22	500
1	600
3	800
3	1000
1	1500
Total 39	

Average Demand

$$\frac{20250}{39} = 519 \text{ Units}$$

Average Interval

$$\frac{337}{34} = 10 \text{ Days}$$

Table 11. Demand for Tool A

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Apr. 1	1	-
May 11	1	28
20	1	7
Jun. 4	1	10
30	1	18
Aug. 10	1	28
Sep. 8	1	20
24	1	12
Oct. 22	1	20
	1	-
Nov. 10	1	13
Dec. 16	1	25
1960		
Jan. 14	1	18
Total	13	199

Table 11-A. Demand Distribution, Average Demand and Average Interval for Tool A

Demand Distribution	
Times Issued	Number Issued
13	1

Average Demand

$$\frac{13}{13} = 1 \text{ Unit}$$

Average Interval

$$\frac{197}{11} = 18 \text{ Days}$$

Table 12. Demand for Tool B

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Feb. 25	1	-
Mar. 2	1	3
26	1	18
Apr. 20	2	17
May 25	1	25
Jul. 14	1	34
	1	-
16	1	2
	1	-
Aug. 12	1	19
14	3	2
Sep. 11	1	19
	1	-
15	1	2
16	1	1
Oct. 19	1	23
26	1	5
Nov. 16	1	15
Dec. 18	1	23
28	1	4
1960		
Jan. 15	1	13
18	1	1
22	1	4
Feb. 2	1	7
9	2	5
Apr. 25	1	54
Total	30	296

Table 12-A. Demand Distribution, Average Demand and Average Interval for Tool B

Demand Distribution

Times Issued	Number Issued
23	1
2	2
1	3
Total 26	

Average Demand

$$\frac{30}{26} = 1 \text{ Unit}$$

Average Interval

$$\frac{296}{22} = 13 \text{ Days}$$

Table 13. Demand for Tool C

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Jan. 8	1	-
13	1	3
15	1	2
21	1	4
23	1	2
27	1	2
30	1	3
Feb. 4	1	3
Mar. 4	1	20
19	1	11
24	1	3
Apr. 13	1	14
	1	-
May 22	1	29
Jun. 4	1	8
22	1	12
23	1	1
24	1	1
Jul. 6	1	7
9	1	3
13	1	2
31	1	14
	1	-
	1	-
	1	-
Aug. 31	2	21
Sep. 8	1	5
15	1	5
28	1	9
	1	-
30	1	2
Oct. 6	1	4
16	2	8
23	1	5

Table 13. Demand for Tool C

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Nov. 10	1	12
17	1	5
	1	-
23	1	4
Dec. 15	1	15
	1	-
16	1	1
1960		
Jan. 6	2	12
15	1	7
18	1	1
Feb. 3	1	12
Mar. 17	1	31
Total	49	303

Table 13-A. Demand Distribution, Average Demand and Average Interval for Tool C

Demand Distribution	
Times Issued	Number Issued
43	1
3	2
Total 46	

Average Demand

$$\frac{49}{46} = 1 \text{ Unit}$$

Average Interval

$$\frac{303}{38} = 8 \text{ Days}$$

Table 14. Demand for Tool D

Date Issued (1959-1960)	Number Issued (Credit)	Interval Between Issues (Days)
1959		
Mar. 9	1	-
10	1	1
11	1	1
May 27	1	55
Sep. 17	1	78
Oct. 16	1	21
23	1	5
	1	-
Nov. 16	1	16
1960		
Jan. 26	1	47
Total	10	224

Table 14-A. Demand Distribution, Average Demand and Average Interval for Tool D

Demand Distribution	
Times Issued	Number Issued
10	1

Average Demand

$$\frac{10}{10} = 1 \text{ Unit}$$

Average Interval

$$\frac{224}{8} = 28 \text{ Days}$$

APPENDIX II

Table 15. Daily Demand Distributions for Fasteners

Number of Demands Per Day	Frequency of Observed Demands (f_o)	Poisson Distribution	Frequency of Theoretical Demands (f_t)	$\frac{(f_o-f_t)^2}{f_t}$
TOOL AA				
0	287	0.8725	287.925	0.0030
1	41	0.1190	39.270	0.0782
2	2	0.0081	2.673	0.2310
3	0	0.0004	0.132	
Total	330	1.0000	330.000	0.3122
TOOL BB				
0	304	0.9375	304.688	0.0016
1	21	0.0606	19.695	0.0865
2	0	0.0019	0.617	0.6170
Total	325	1.0000	325.000	0.7051
TOOL CC				
0	313	0.8965	311.982	0.0033
1	32	0.0979	34.069	0.1257
2	3	0.0054	1.879	0.5668
3	0	0.0002	0.070	
Total	348	1.0000	348.000	0.6958
TOOL DD				
0	311	0.9304	309.823	0.0045
1	20	0.0671	22.344	0.2459
2	2	0.0024	0.799	1.6349
3	0	0.0001	0.034	
Total	333	1.0000	333.000	1.8853
TOOL EE				
0	289	0.8169	286.732	0.0179
1	54	0.1653	58.020	0.2785
2	7	0.0167	5.862	0.5579
3	1	0.0011	0.386	
Total	351	1.0000	351.000	0.8543

Table 15. Daily Demand Distributions for Fasteners

Number of Demands Per Day	Frequency of Observed Demands (f_o)	Poisson Distribution	Frequency of Theoretical Demands (f_t)	$\frac{(f_o-f_t)^2}{f_t}$
TOOL FF				
0	308	0.9051	308.639	0.0013
1	32	0.0902	30.758	0.0502
2	1	0.0045	1.535	0.2268
3	0	0.0002	0.068	
Total	341	1.0000	341.000	0.2783
TOOL GG				
0	289	0.8376	288.134	0.0026
1	49	0.1485	51.084	0.0850
2	6	0.0132	4.541	0.3102
3	0	0.0007	0.241	
Total	344	1.0000	344.000	0.3978
TOOL HH				
0	296	0.9090	295.425	0.0011
1	27	0.0867	28.178	0.0492
2	2	0.0042	1.365	0.2603
3	0	0.0001	0.032	
Total	325	1.0000	325.000	0.3106
TOOL JJ				
0	321	0.9351	320.739	0.0002
1	21	0.0627	21.506	0.0119
2	1	0.0021	0.721	0.0795
3	0	0.0001	0.034	
Total	343	1.0000	343.000	0.0916
TOOL KK				
0	300	0.9003	299.800	0.0001
1	31	0.0946	31.502	0.0080
2	2	0.0050	1.665	0.0537
3	0	0.0001	0.033	
Total	333	1.0000	333.000	0.0618

Table 16. Daily Demand Distributions for Grinding Wheels

Number of Demands Per Day	Frequency of Observed Demands (f_o)	Poisson Distribution	Frequency of Theoretical Demands (f_t)	$\frac{(f_o-f_t)^2}{f_t}$
<u>TOOL A</u>				
0	216	0.9446	215.369	0.0018
1	11	0.0538	12.266	0.1307
2	1	0.0016	0.365	1.1047
	Total 228	1.0000	228.000	1.2372
<u>TOOL B</u>				
0	313	0.9255	310.968	0.0133
1	20	0.0716	24.058	0.6845
2	3	0.0028	0.941	4.2142
3	0	0.0001	0.033	
	Total 336	1.0000	336.000	4.9120
<u>TOOL C</u>				
0	265	0.8596	261.318	0.0519
1	34	0.1301	39.551	0.7791
2	4	0.0098	2.979	
3	0	0.0005	0.152	1.1157
4	1	0.0000	0.000	
	Total 304	1.0000	304.000	1.9467
<u>TOOL D</u>				
0	262	0.9638	261.190	0.0025
1	8	0.0356	9.648	0.2815
2	1	0.0006	0.162	4.3348
	Total 271	1.0000	271.000	4.6188

Table 17. Goodness of Fit

$$\text{Chi-Square} = \text{Sum}\ \frac{(f_o - f_t)^2}{f_t}$$

Chi-Square (Percentage), (Degrees of Freedom)

<u>Tool</u> <u>AA</u>

Computed Chi-Square	=	.312	
Tabulated Chi-Square (.70), (1)	=	.148	
Tabulated Chi-Square (.50),(1)	=	.455	Not Significant

<u>Tool</u> <u>BB</u>

Computed Chi-Square	=	.705	
Tabulated Chi-Square (.50),(1)	=	.455	
Tabulated Chi-Square (.30),(1)	=	1.074	Not Significant

<u>Tool</u> <u>CC</u>

Computed Chi-Square	=	.696	
Tabulated Chi-Square (.50),(1)	=	.455	
Tabulated Chi-Square (.30),(1)	=	1.074	Not Significant

<u>Tool</u> <u>DD</u>

Computed Chi-Square	=	1.885	
Tabulated Chi-Square (.20),(1)	=	1.642	
Tabulated Chi-Square (.10),(1)	=	2.706	Not Significant

<u>Tool</u> <u>EE</u>

Computed Chi-Square	=	.854	
Tabulated Chi-Square (.50),(1)	=	.455	
Tabulated Chi-Square (.30),(1)	=	1.074	Not Significant

<u>Tool</u> <u>FF</u>

Computed Chi-Square	=	.278	
Tabulated Chi-Square (.70),(1)	=	.148	
Tabulated Chi-Square (.50),(1)	=	.455	Not Significant

<u>Tool</u> <u>GG</u>

Computed Chi-Square	=	.398	
Tabulated Chi-Square (.70),(1)	=	.148	
Tabulated Chi-Square (.50),(1)	=	.455	Not Significant

Table 17. Goodness of Fit

<u>Tool HH</u>

Computed Chi-Square	= .311	
Tabulated Chi-Square (.70),(1)	= .148	
Tabulated Chi-Square (.50),(1)	= .455	Not Significant

<u>Tool JJ</u>

Computed Chi-Square	= .0916	
Tabulated Chi-Square (.80),(1)	= .0642	
Tabulated Chi-Square (.75),(1)	= .102	Not Significant

<u>Tool KK</u>

Computed Chi-Square	= .0618	
Tabulated Chi-Square (.90),(1)	= .0158	
Tabulated Chi-Square (.80),(1)	= .0642	Not Significant

<u>Tool A</u>

Computed Chi-Square	= 1.237	
Tabulated Chi-Square (.30),(1)	= 1.074	
Tabulated Chi-Square (.25),(1)	= 1.323	Not Significant

<u>Tool B</u>

Computed Chi-Square	= 4.912	
Tabulated Chi-Square (.05),(1)	= 3.841	
Tabulated Chi-Square (.025),(1)	= 5.024	Significant

<u>Tool C</u>

Computed Chi-Square	= 1.947	
Tabulated Chi-Square (.20),(1)	= 1.642	
Tabulated Chi-Square (.10),(1)	= 2.706	Not Significant

<u>Tool D</u>

Computed Chi-Square	= 4.619	
Tabulated Chi-Square (.05),(1)	= 3.841	
Tabulated Chi-Square (.025),(1)	= 5.024	Significant

Table 18. Observed Distribution of Lead Time for Fasteners

P[0]	=	0/52	=	.0000
P[1]	=	0/52	=	.0000
P[2]	=	2/52	=	.0385
P[3]	=	1/52	=	.0192
P[4]	=	12/52	=	.2308
P[5]	=	5/52	=	.0962
P[6]	=	7/52	=	.1346
P[7]	=	9/52	=	.1731
P[8]	=	4/52	=	.0769
P[9]	=	4/52	=	.0769
P[10]	=	2/52	=	.0385
P[11]	=	1/52	=	.0192
P[12]	=	4/52	=	.0769
P[13]	=	0/52	=	.0000
P[14]	=	1/52	=	.0192
Total				1.0000

Table 19. Observed Distribution of Lead Time for Grinding Wheels

P[0]	=	1/27	=	.03704
P[1]	=	1/27	=	.03704
P[2]	=	0/27	=	.00000
P[3]	=	3/27	=	.11111
P[4]	=	0/27	=	.00000
P[5]	=	2/27	=	.07407
P[6]	=	0/27	=	.00000
P[7]	=	1/27	=	.03704
P[8]	=	1/27	=	.03704
P[9]	=	9/27	=	.33333
P[10]	=	3/27	=	.11111
P[11]	=	0/27	=	.00000
P[12]	=	1/27	=	.03704
P[13]	=	4/27	=	.14815
P[14]	=	0/27	=	.00000
P[15]	=	0/27	=	.00000
P[16]	=	0/27	=	.00000
P[17]	=	1/27	=	.03704
Total				1.00001

Table 20. Probability of Demand During Lead Time

Fasteners

	AA	BB.	CC	DD	EE
P[0]	.4308	.6609	.5046	.6307	.2987
P[1]	.3373	.2643	.3252	.2792	.3253
P[2]	.1552	.0621	.1233	.0727	.2079
P[3]	.0550	.0110	.0358	.0146	.1022
P[4]	.0164	.0016	.0088	.0025	.0428
P[5]	.0043	.0001	.0019	.0003	.0159
P[6]	.0010	- *	.0004	-	.0054
P[7]	-	-	-	-	.0015
P[8]	-	-	-	-	.0003
Total	1.0000	1.0000	1.0000	1.0000	1.0000

	FF	GG	HH	JJ	KK
P[0]	.5340	.3424	.5477	.6506	.5171
P[1]	.3170	.3346	.3129	.2694	.3221
P[2]	.1109	.1921	.1051	.0656	.1180
P[3]	.0297	.0848	.0271	.0122	.0332
P[4]	.0067	.0317	.0059	.0019	.0079
P[5]	.0013	.0104	.0012	.0003	.0016
P[6]	.0001	.0031	.0001	-	.0001
P[7]	-	.0009	-	-	-
Total	1.0000	1.0000	1.0000	1.0000	1.0000

Grinding Wheels

	A	B	C	D
P[0]	.6332	.5444	.3324	.7398
P[1]	.2733	.3057	.3073	.2152
P[2]	.0750	.1113	.1999	.0391
P[3]	.0155	.0304	.0999	.0052
P[4]	.0027	.0068	.0406	.0007
P[5]	.0003	.0014	.0142	-
P[6]	-	-	.0047	-
P[7]	-	-	.0010	-
Total	1.0000	1.0000	1.0000	1.0000

* A dash denotes that this probability is less than 0.0001.

Table 21. Lead Time for Fasteners

Difference Between Order and Receiving (Days)	$\bar{x}$	σ	Difference Between Receiving and Stores (Days)	$\bar{x}$	σ	Difference Between Order and Stores (Days)	$\bar{x}$	σ
Tool AA								
3			5			8		
7			5			12		
3			2			5		
3			3			6		
5			1			6		
21	4.20	1.600	16	3.20	1.600	37	7.40	2.498
Tool BB								
3			5			8		
7			5			12		
5			3			8		
15	5.00	1.633	13	4.33	.943	28	9.33	1.886
Tool CC								
2			12			14		
3			2			5		
2			2			4		
4			8			12		
0			2			2		
7			3			10		
1			3			4		
19	2.71	2.119	32	4.57	3.620	51	7.29	4.300
Tool DD								
6			9			15		

Table 21. Lead Time for Fasteners

Difference Between Order and Receiving (Days)	$\bar{x}$	σ	Difference Between Receiving and Stores (Days)	$\bar{x}$	σ	Difference Between Order and Stores (Days)	$\bar{x}$	σ
Tool EE								
2			7			9		
1			3			4		
3			5			8		
1			2			3		
2			2			4		
2			5			7		
1			3			4		
4			3			7		
1			3			4		
5			1			6		
22	2.20	1.327	34	3.40	1.685	56	5.60	1.960
Tool FF								
2			7			9		
1			3			4		
1			4			5		
1			3			4		
1			10			11		
4			8			12		
0			2			2		
4			1			5		
1			3			4		
15	1.67	1.333	41	4.56	2.872	56	6.22	3.326

Table 21. Lead Time for Fasteners

Difference Between Order and Receiving (Days)	$\bar{x}$	σ	Difference Between Receiving and Stores (Days)	$\bar{x}$	σ	Difference Between Order and Stores (Days)	x	σ
Tool GG								
1			5			6		
2			5			7		
1			6			7		
2			5			7		
1			3			4		
2			4			6		
1			5			6		
10	1.43	.495	33	4.71	.881	43	6.14	.990
Tool HH								
2			7			9		
1			9			10		
2			2			4		
2			5			7		
4			3			7		
2			3			5		
13	2.17	.898	29	4.83	2.478	42	7.00	2.082
Tool JJ								
1			14			15		

Table 21. Lead Time for Fasteners

Difference Between Order and Receiving (Days)	$\bar{x}$	σ	Difference Between Receiving and Stores (Days)	$\bar{x}$	σ	Difference Between Order and Stores (Days)	$\bar{x}$	σ
Tool KK								
2			7			9		
1			3			4		
5			2			7		
4			3			7		
5			1			6		
17	3.40	1.855	16	3.20	2.040	33	6.60	1.855
Total	22.78	11.260		32.80	16.119		55.58	18.897
$\bar{\bar{x}}$	2.85			4.10			6.95	
$\bar{\sigma}$		1.407			2.015			2.362

Table 22. Lead Time for Grinding Wheels

Difference Between Order and Receiving (Days)	$\bar{x}$	σ	Difference Between Receiving and Stores (Days)	$\bar{x}$	σ	Difference Between Order and Stores (Days)	$\bar{x}$	σ
<u>Tool A</u>								
0			1			1		
2			7			9		
1			9			10		
13			0			13		
2			7			9		
18	3.60	4.758	24	4.80	3.600	42	8.40	3.980
<u>Tool B</u>								
1			8			9		
0			3			3		
1			12			13		
1			8			9		
2			7			9		
6			11			17		
11	1.83	1.955	49	8.17	2.914	60	10.00	4.282

Table 22. Lead Time for Grinding Wheels

Difference Between Order and Receiving (Days)	$\bar{x}$	σ	Difference Between Receiving and Stores (Days)	$\bar{x}$	σ	Difference Between Order and Stores (Days)	$\bar{x}$	σ
<u>Tool C</u>								
1			7			8		
2			10			12		
1			2			3		
2			3			5		
2			8			10		
1			9			10		
0			0			0		
1			6			7		
2			7			9		
2			7			9		
14	1.40	.663		5.90	3.048	73	7.30	3.466

Table 22. Lead Time for Grinding Wheels

Difference Between Order and Receiving (Days)	$\bar{x}$	σ	Difference Between Receiving and Stores (Days)	$\bar{x}$	σ	Difference Between Order and Stores (Days)	$\bar{x}$	σ
<u>Tool D</u>								
2			3			5		
1			2			3		
1			8			9		
12			1			13		
3			10			13		
1			8			9		
20	3.33	3.944	32	5.33	3.448	52	8.67	3.727
Total	10.16	11.320		24.20	13.010		34.37	15.455
$\bar{\bar{x}}$	2.54			6.05			8.59	
$\bar{\sigma}$		2.830			3.253			3.864

Table 23. Limits of $\bar{x}$ Control Chart for Fasteners

	Order and Receive (Upper Limit, Lower Limit)	$\bar{\bar{x}}$	Receive and Stores (Upper Limit, Lower Limit)	$\bar{\bar{x}}$	Order and Stores (Upper Limit Lower Limit)	$\bar{\bar{x}}$
Tool AA	5.093 .601	4.200	7.316 .886	3.200	10.718 3.178	7.400
Tool BB	6.216 .000	5.000	8.924 .000	4.333	12.602 1.294	9.333
Tool CC	4.644 1.050	2.714	6.674 1.528	4.571	9.964 3.932	7.286
Tool EE	4.294 1.400	2.200	6.172 2.030	3.400	9.376 4.520	5.600
Tool FF	4.387 1.307	1.667	6.305 1.897	4.556	9.532 4.364	6.222
Tool GG	4.644 1.050	1.429	6.674 1.528	4.714	9.964 3.932	6.143
Tool HH	4.831 .863	2.167	6.942 1.260	4.833	10.278 3.618	7.000
Tool KK	5.093 .601	3.400	7.316 .886	3.200	10.718 3.178	6.600

Table 24. Limits of σ Control Chart for Fasteners

	Order and Receive (Upper Limit, Lower Limit)	σ	Receive and Stores (Upper Limit Lower Limit)	σ	Order and Stores (Upper Limit Lower Limit)	σ
Tool AA	2.940 .000	1.600	4.209 .000	1.600	4.934 .000	2.498
Tool BB	3.614 .000	1.633	5.174 .000	.943	6.065 .000	1.886
Tool CC	2.649 .166	2.119	3.792 .238	3.620	4.445 .279	4.300
Tool EE	2.415 .400	1.327	3.457 .572	1.685	4.053 .671	1.960
Tool FF	2.479 .336	1.333	3.548 .481	2.872	4.159 .564	3.326
Tool GG	2.649 .166	.495	3.792 .238	.881	4.445 .279	.990
Tool HH	2.772 .042	.898	3.969 .060	2.478	4.653 .071	2.082
Tool KK	2.940 .000	1.855	4.209 .000	2.040	4.934 .000	1.855

Table 25. Limits of $\bar{x}$ Control Chart for Grinding Wheels

	Order and Receive (Upper Limit, Lower Limit)	$\bar{x}$	Receive and Stores (Upper Limit, Lower Limit)	$\bar{x}$	Order and Stores (Upper Limit, Lower Limit)	$\bar{x}$
Tool A	7.058 .000	3.600	11.242 .858	4.800	14.759 2.425	8.400
Tool B	6.532 .000	1.833	10.637 1.463	8.167	14.040 3.143	10.000
Tool C	5.451 .000	1.400	9.394 2.706	5.900	12.564 4.619	7.300
Tool D	6.532 .000	3.333	10.637 1.463	5.333	14.040 3.143	8.667

Table 26. Limits of σ Control Chart for Grinding Wheels

	Order and Receive (Upper Limit, Lower Limit)	σ	Receive and Stores (Upper Limit, Lower Limit)	σ	Order and Stores (Upper Limit Lower Limit)	σ
Tool A	5.912 .000	4.758	6.796 .000	3.600	8.072 .000	3.980
Tool B	5.575 .085	1.955	6.408 .098	2.914	7.612 .116	4.282
Tool C	4.856 .804	.663	5.582 .924	3.048	6.631 1.097	3.466
Tool D	5.575 .085	3.944	6.408 .098	3.448	7.612 .116	3.727

Table 27. Posting Distributions for Fasteners

Order and Post		Stores and Post		Issue and Post	
Number of Orders	Difference Between O & R (Days)	Number of Orders	Difference Between S & P (Days)	Number of Requests	Difference Between I & P (Days)
7	0	1	0	5	0
8	1	9	1	44	1
21	2	6	2	85	2
13	3	19	3	80	3
5	4	12	4	73	4
6	5	2	5	52	5
2	6	9	6	40	6
1	7	4	7	26	7
				17	8
2	9	3	9	7	9
				2	10
				6	11
				1	13
				2	14
				3	20
				1	24
				1	31
		1	44		
				1	120
65	Total	66	Total	446	Total
Average Days: $\frac{176}{65} = 2.71$		Average Days: $\frac{289}{66} = 4.38$		Average Days: $\frac{1989}{446} = 4.46$	

Table 28. Posting Distributions for Grinding Wheels

Order and Post		Stores and Post		Issue and Post	
Number of Orders	Difference Between O & R (Days)	Number of Orders	Difference Between S & P (Days)	Number of Requests	Difference Between I & P (Days)
3	0				
8	1	5	1	12	1
8	2	7	2	20	2
8	3	2	3	18	3
4	4	9	4	16	4
		3	5	16	5
4	6	7	6	13	6
1	7			7	7
1	8	1	8	2	8
		3	10	3	10
				1	11
1	12				
				1	13
1	15				
		1	23		
				1	27
				1	33
				2	40
				1	78
39	Total	38	Total	114	Total

Average Days:

$$\frac{130}{39} = 3.33$$

Average Days:

$$\frac{179}{38} = 4.71$$

Average Days:

$$\frac{665}{114} = 5.83$$

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